PLATE TECTONICS AND THE DISCRIMINATION OF UNDERGROUND EXPLOSIONS FROM EARTHQUAKES

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13 ABSTRACT

During the period covered by this semi-annual report (1 January to 30 June 1975), seven general topics of research have been investigated. I. A study of anomalous events, earthquakes which plot near the explosion population in a M_s-m_b diagram, has concluded that all such anomalous events in the eastern Himalayas are natural earthquakes. II. A study of a foreshock-mainshock-aftershock sequence is being conducted to determine if there are factors other than source depth focal mechanism that control the surface wave magnitude of small events. The study indicates that finiteness of the source can play a role in controlling M_s for events smaller than m_b 5.2. III. Three studies are in progress on the topic of Intraplate Tectonics: a) focal mechanisms for intraplate earthquakes in Central Asia by WWNSS and mainland Chinese data; b) analysis of an accelerogram of an intraplate earthquake, Blue Mtn. Lake, N.Y.; and c) In Situ strain relief measurements in an intraplate area, the Adirondack Mts., N.Y. IV. A study comparing the motions in a half space near a fault with those which occur in a whole space if the surface were absent has been completed. The results are that the motion on the half space may be approximated by doubling those in an infinite space when the angle of incidence is less than 30°. V. A study is currently in progress to test the validity of various models of the core-mantle boundary using seismograms synthesized by the Langer method of frequency domain calculations. VI. In another study, the excitation of higher mode surface waves by shallow events is being examined. VII. A study is also under way on the possible interrelation among bouyant zones, great earthquakes, and dynamic boundaries of subduction.

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great earthquakes						

MAJOR SCIENTIFIC ACCOMPLISHMENTS

In the following paragraphs, scientific accomplishments for January through June 1975 are summarized following the itemization in the statement of work of this contract.

Line - Item 0001b

1. Discrimination of Anomalous Events in the Eastern Himalayas

Ongoing research toward the discrimination of anomalous events--those natural earthquakes that plot in, or near, the explosion population on an M_s-m_b diagram--has led to the identification of all such events located near the eastern Himalayas as natural earthquakes. Most of the reported anomalous events (about 25) are located in Tibet in a particular tectonic setting associated with the eastern termination of the Himalayas. At this point several tectonic trends of the Himalayas, an area of continent-continent collision, converge toward an intersection with the northward projection of the Andaman-Burman arc. Thus, the tectonic regime of these anomalous events is not part of the Himalayas but rather appears to be related to "end-effects" at their eastern terminus. Previous investigators have suggested that anomalous events result from strong excitation and efficient propagation of body waves. Our study of the regional tectonics of the area reveals several potential sources of poor surface wave excitation. The crust of the Tibetan Plateau, which from meager data appears to be almost twice as thick as normal continental crust, offers a medium for the occurrence of earthquakes at moderate focal depths. Rayleigh waves of the fundamental mode are poorly excited by earthquakes at such depths. The thick crust also provides a wave guide for the efficient propagation of Love waves and higher-mode Rayleigh waves, and it is found that observations of these waves provide a discriminant for some of the anomalous events. In particular observations of higher modes offer an especially attractive discriminant. Since the degree of excitation of various modes depends mainly on focal depth, no explosion data are required for comparison of earthquakes and explosions. These higher-mode observations, combined with more reliable m_b determinations, identify all of the reported anomalous events in Tibet--with the exception of a single sequence of events--as natural earthquakes. The remaining sequence of anomalous events, none of which is in the explosion population, occurred in a very limited area (about 50 km or less on a side) where a concentration of tectonic stress may be anticipated. Thus, these few remaining anomalous earthquakes may be related to high tectonic stress, perhaps in association with the formation of a new fault. High-stress earthquakes often have small source dimensions, and hence only weak surface waves are excited. This study places the occurrence of these remaining anomalous events with the complex tectonic setting of the eastern terminus of the Himalayas. Observations of dilatational first motions, however, allow these events to be discriminated. Thus, all of the reported anomalous events in Tibet are identified as natural earthquakes. To our knowledge, all events from Tibet or elsewhere that have been discussed in the literature as being anomalous can, in fact, be identified as earthquakes using one or more of the above mentioned techniques.

2. Higher Mode Excitation by Shallow Earthquakes

The excitation of higher modes by shallow events large enough to allow focal mechanism determination is being examined. The spectra of the fundamental mode Love and Rayleigh waves observed at several stations are used to establish the depth of the events. Since all of the events studied are in a limited geographical area, a comparative event technique can be used to remove propagation path effects from the spectra. Once the depths and mechanisms are known, the events can be used as standards for establishing the detailed characteristics of excitation and propagation of the higher modes. In turn, these characteristics can be helpful in classifying other seismic sources, particularly those small events for which higher modes are observed, but which are too small for reliable measurement of the complete spectra of the fundamental mode. For some small, anomalous events in Kazakh, an M_s based on the higher mode amplitudes may be more reliable than an M_s based on the short-period fundamental mode Rayleigh waves.

Line - Item 0001d

Causes of M_s-m_b Variations Within a Central-Asian Earthquake Sequence

A foreshock-mainshock-aftershock sequence which occurred in June, 1971 in the Kirgiz-Kinkiarg border region is being studied to determine what factors other than source depth and focal mechanism control the surface wave magnitude of small events. The National Earthquake Information Center (NEIC) assigned a body wave magnitude of 5.6 to both the foreshock and mainshock, but the surface waves generated by the mainshock were approximately 5 times longer than the foreshock. ISC assigned m_b values 5.4 and 5.3 to the foreshock and main shock, respectively. The surface wave magnitude could be affected by differences in depth, mechanism, stress drop or finiteness, but all possible path and instrument phenomena are eliminated by choosing a sequence which is limited in duration and location. The mechanism and depth of the events can be deduced from comparison of the azimuthal variations in the frequency-dependent radiation patterns of the amplitude and initial phase of the Rayleigh and Love waves.

Evernden (1975) suggested that the primary factors controlling M_s of small events (less than about m_b 5.5) are depth and focal mechanisms and that stress drop and source length are unimportant. However, differences in mechanism and depth do not appear to adequately explain the dramatic variation in surface wave amplitude within the series of aftershocks. For example, one aftershock, with m_b 5.2, generated surface waves roughly 12 times larger than another aftershock with m_b 5.1. The contrast cannot be attributed to an unusual combination of depth and mechanism effects on the surface wave amplitudes, because the long-period body waves are affected to a similar degree. The earthquakes in the sequence can be divided into two categories; those which excite long-period signals efficiently, such as the main shock and several aftershocks; and those which do not, such as the foreshock and the majority of aftershocks. The primary difference between the two groups may be in the finite size of the source. As observed teleseismically the second group typically generates a very simple, short-period P-wave with most of the energy concentrated within the first 1 to 2 sec., suggesting nearly a point source. However, earthquakes within the first group generate a much more complex P-wave, with substantial energy spread out over the first 10 to 15

sec. These observations suggest that finiteness of the source can play an important role in controlling M_s : m_b even for earthquakes with body wave magnitude 5.2 or smaller.

Line - Item 0001e

1. Analysis of an Accelerogram of an Intraplate Earthquake

In advancing our understanding of possible driving mechanisms of plate tectonics, Sykes & Sbar (1973, 1974) have considered the focal mechanism of intraplate earthquakes. Most intraplate earthquakes were interpreted to be of thrusting mechanisms, suggesting horizontal compression as the dominant component of stress. In fact, Sbar and Sykes (1973, 1974) have suggested much of eastern North America is in a state of high horizontal compressive stress. We have recently completed a detailed study of one intraplate earthquake in the Eastern United States. The principal results are that an accelerogram obtained at Blue Mt. Lake is remarkable for the simplicity of its S-wave pulse. This is due to 1) a nearly complete absence of scattering and reflections as second arrivals on the accelerogram and 2) a very elementary earthquake source. The earthquake identified with this accelerogram had a magnitude m_b = 2.2 and a hypocentral distance of about 1 km from the accelerometer. Analysis of the S-wave indicates the earthquake had a moment of 5 to 6.3 x 10^{18} dyne-cm, and a source radius of 20 to 40 m. When the accelerogram is integrated to obtain displacement, there is a step offset of about 5 microns associated with a near field component of the S-wave pulse. The S-wave, including the step offset, can be matched in remarkable detail by a dislocation model.

2. Near Field Displacements

We have made a systematic comparison of motions on a half space near a fault with those which would occur in a whole space if the surface were absent. We use the Green's function for a half space given by Johnson (1974). Use of this Green's function allows four major surface effects to be studied: the amplification of all waves; the phase shift of SV waves incident at angles more grazing than critical; the SP-phase which is a P-wave converted from an SV wave incident at the critical angle; and Rayleigh waves. Our objective is a critical evaluation of the assumption, used frequently in dislocation modeling, that the free surface can be reasonably accounted for by doubling the whole space amplitude (eg. Kanamori, 1972; Trifunac, 1974; Trifunac and Udwadia, 1973; Anderson, 1974).

In doing this, we have developed a practical way of computing displacements on the surface of a half space as a two step process. The first step is calculating and storing the Green's function for a given station for several points on the fault; and the second step is convolving with the source time function. This method can be faster than the corresponding whole space calculations (which recompute the Green's function) when several models are tried for the same geometry, as in a studying a particular accelerogram record. This method also gives a clear idea of what frequencies are significant in a given record.

The results are that motions on the surface of a half space may be approximated by doubling the amplitude of motion in an infinite space when angles of incidence are less than 30 degrees. For greater angles of incidence, the faulting parameters derived from a whole space model in this manner are potentially somewhat misleading. The P- and SV- waves from a point source in the half space can generally be obtained from the whole space counterparts by applying the appropriate plane wave surface correction. The SV-waves for angles somewhat greater than critical cannot be derived in this way, neither can the AP-phase of the Rayleigh wave.

Line - Item 0001f

Earth Modeling using Synthetic Seismograms

A study is currently in progress to test the validity of various models of the core-mantle boundary using synthetic seismograms. The Langer method of frequency domain calculations (Richards, 1975) has distinct advantages over other methods in describing the effects of earth structure on waves propagating through the earth. The method is uniformly asymptotic in frequency, as opposed to virtually all other approximating methods which are non-uniform and fail at turning points. In addition, for a ray with a turning point near a discontinuity in the earth, the Langer approach corrects the reflection and transmission coefficients for dependence on frequency, radius or curvature of a discontinuity and the effect of earth structure near the discontinuity. Indeed, the observation of multiple core phases at distances beyond the range predicted by classical ray theory for currently acceptable earth models can now be explained in terms of tunnelling phenomenon (Richards, 1973, 1975) in which rays with turning points just above the core-mantle boundary can leak energy into the earth's core.

The Langer approach is currently being applied to the synthesis of theoretical seismograms of SKS and SKKS and recorded on long period instruments. The method also easily accounts for diffracted energy associated with SKS in a body wave called $SP_{diff}KS$ (King and Muller, 1975). The behavior of the long period content of these body waves should deviate from classical ray theory. The extent and sensitivity of this deviation for various earth models will be investigated. The comparison of synthesized seismograms with data from WWSSN and other seismic stations will serve as a guide to the validity of various earth models at the core-mantle transition zone.

Line - Item 0001g

A Study of Focal Mechanisms for Intraplate Earthquakes in Central Asia

A focal mechanism study of the contemporary tectonics of central Asia is being undertaken using data from both WWSSN film chips and information from seismograms recorded in mainland China. The epicentral distribution in this area shows that there is no sharp boundary between the Indian and Eurasian

plates as would be expected if the contemporary tectonics were simply the result of the intersection of the two plates. Molnar et al. (1973) proposed that stable blocks within the Eurasian plate may play an important role in the explanation of the tectonics. There presented no quantitative evidence for this proposal.

The quantitative evidence necessary to study this tectonic problem has not been available until the present. Data from the close-in Chinese stations are necessary to determine reliable focal mechanisms for the thrust fault type earthquakes which predominate in the fold belts of central Asia. The WWSSN station distribution does not lend itself to reliable focal mechanisms for this area.

Through the analysis of the combined WWSSN and Chinese data sets, we hope to obtain more accurate orientations for the slip vectors and the directions of the three principal stress axes. The former can be used to define the direction of relative motion between two of the plates and in effect aid in the determination of the plate boundaries. From the stress orientations, we hope to obtain an improved understanding of the relations between the seismicity and the tectonic features.

In Situ Strain Relief Measurements in an Intraplate Area

Twelve strain relief measurements were made at 5 sites on Potsdam Sandstone northeast of the Adirondack Mountains, New York to test Sbar and Sykes (1973) suggestion that the upper crust in a large area of eastern North America is currently in a state of east-west compression. In situ strain was relieved by overcoring, and detected using strain gages bonded to the sandstone at the surface. The average of nine measurements at four sites in the Late Cambrian Keeseville Member of the Potsdam Sandstone indicate that the direction of maximum expansion upon overcoring is N78°W. These nine measurements also indicate that stress can be consistent in orientation over areas of tens of square kilometers. The average of three measurements at one site in the Nicholville Member 11 km from the other four sites indicate a maximum expansion oriented N18°E. Double overcore tests suggest that a sizeable component of the measured strain is residual. We suggest that the residual strain measured in the Nicholville Member may be related to a late Proterozoic (Hadrynian) or early Cambrian stress field.

Line - Item 0001h

A Study of the Relationship among Bouyant Zones, Great Earthquakes and Dynamic Boundaries of Subduction

The distribution of large shallow earthquakes along subduction boundaries is in serious disagreement with the distribution pattern that might be predicted from a simple model of plate tectonics. That is, along extensive sections of some island arcs large shocks occurred infrequently or not at all during recorded history. Most of these zones of long-term quiescence are nearly coterminous with segments of the margin where zones of seamounts, aseismic ridges

or other bathymetric highs of the underthrust slab appear to be interacting with the subduction process. Because of this widespread spatial correlation and because all or nearly all elevated portions of the sea floor have crustal roots, aseismic ridges or other uplifted regions may reveal zones of relative buoyancy within oceanic plates which resist subduction upon collision with an active trench. Thus, in place of the typical subduction process at locations where buoyant zones interact with the subduction process, rigid plate motion may be preserved by a variety of tectonic responses including: arc-polarity reversal, gradual or abrupt shifts in the plate margin, the development of cusps between arcs (as suggested by Vogt, 1973), development of broad zones of deformation, partial subduction (descent to perhaps 50-100 km but no farther) or, possibly, termination of subduction. If our interpretation is valid, then it may be possible to explain in a relatively straightforward manner other modifications of the subduction process such as gaps in the line of active volcanoes, the presence of detached slabs of lithosphere in certain parts of subduction zones, abrupt changes in strike and dip of the descending lithospheric plate, the absence of intermediate-depth earthquakes in certain locations and the emplacement of ophiolite sequences.

In place of "typical oceanic" lithosphere, therefore, there may exist a broad spectrum of average densities for oceanic lithosphere and the relative buoyancies of the two slabs near the subducting margin appears to be a dominant influence in the development of subduction tectonics and in the locations of great earthquakes.

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Problems Encountered:

None

Action Required by the Government:

None

Future Plans:

Future plans call for the continuation of the research outlined above and in other areas specifically related to the VELA-UNIFORM program.

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